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Neutron Electric Dipole Moment

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Abstract. The status of experiments to measure the electric dipole moment of the neutron is presented and the planned experiment at Los Alamos is described. The goal of this experiment is an improvement in sensitivity of a factor of 50 to 100 over the current limit. It has the potential to reveal new sources of T and CP violation and to challenge calculations that propose extensions to the Standard Model. The experiment employs several advances in technique to reach its goals and the feasibility of meeting these technical challenges is currently under study.

INTRODUCTION

A permanent electric dipole moment (EDM) of the neutron requires an interaction that violates both P and T invariance. The weak interaction violates P maximally. Because of widespread acceptance of the CPT theorem, CP violation implies T violation, so most electroweak models of CP violation give predictions for non-zero values for the neutron EDM. The present limit for the neutron EDM is $< 0.63\times10^{-26}$ e-cm [1]. The standard model prediction is very small ($\sim10^{-31}$ e-cm), which opens a wide window for new physics and several models predict values near the present limit [2]. New experiments are underway that will reach well into this window and will probe for physics beyond the Standard Model.

PREVIOUS AND PROPOSED EXPERIMENTS

The most recent published results for the neutron EDM and projected results from the experiments discussed below are summarized in Table 1. The ILL result [1] includes the data from an older version of the experiment [3]; the validity of the quoted result has been questioned because a statistics limited value has been combined with an earlier more precise, but systematics limited result [4].

TABLE 1. Previous and projected results for the neutron EDM.

Limit (e-cm)	CL%	Lab (Ref.)	year
$< 1.2 \times 10^{-25}$	95	ILL [3]	1990
$< 0.97 \times 10^{-25}$	90	PNPI [5]	1996
$< 0.63 \times 10^{-25}$	90	ILL [1]	1999
projected:			
$< 1 \times 10^{-26}$	90	ILL [6]	2004
$< 7 \times 10^{-28}$	90	PSI [7]	2005(?)
$< 2 \times 10^{-28}$	95	LANL [8]	2010

A schematic drawing of the ILL experiment is shown in Fig. 1. This experiment stores ultracold neutrons (UCN) in the main storage cell with parallel E and B fields. A polarizing foil is used to polarize the incident UCN and to analyze the outgoing UCN. The density of UCN was 0.6 UCN/cm^3 and the measurement time was 130 s. The Ramsey separated field technique is used to look for a change in the Larmor precession frequency upon reversal of the E field with respect to the static B field. The average B field is monitored by an Hg comagnetometer, which is crucial for accounting for magnetic field fluctuations.

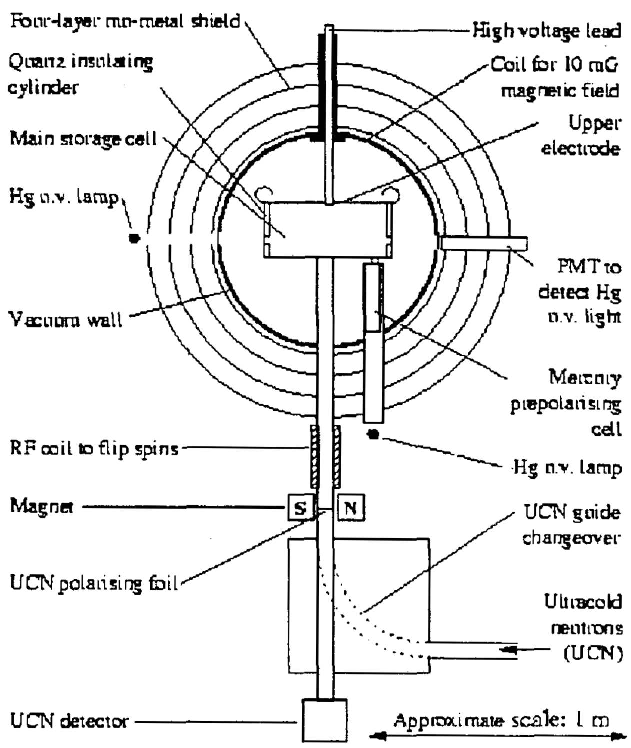

FIGURE 1. Schematic of the current ILL experiment from Ref. 1.

The collaboration is working on a series of incremental improvements that should result in a projected limit of $< 1 \times 10^{-26}$ e-cm by 2004 [6]. The improvements include an increase in the UCN flux, longer UCN storage time with better wall coatings for the storage cell, and an increased E field with a shorter cell.

A schematic of the planned PSI experiment [7] is shown in Fig. 2. The technique is similar to that used in the experiment at ILL. A solid D_2 source is being developed to produce an unprecedented flux of UCN with 10^3 UCN/cm^3. The experiment features multiple pairs of cells to store the UCN. Having adjacent cells with opposite directions for the E field will help to reduce systematic errors. However, the large volume places severe demands on the magnetic shielding, and active shielding is planned to keep the spatial uniformity to 10^{-12} T/cm and the temporal stability to 10^{-14} T at mHz frequencies. Cs magnetometers will be located adjacent to the cells. This experiment expects to reach a sensitivity of $< 5 \times 10^{-28}$ e-cm.

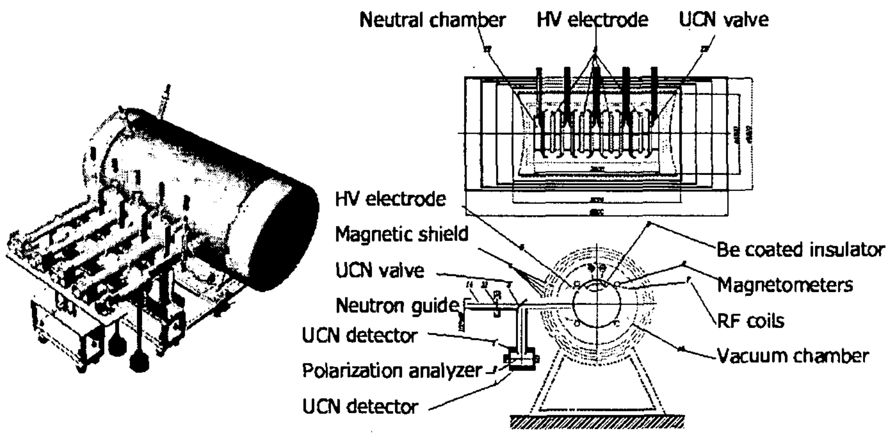

FIGURE 2. Schematic of the proposed PSI experiment from Ref. 4.

LANL EXPERIMENT

A schematic of the design concept for the LANL EDM experiment [8] is shown in Fig. 3. The electric field is formed by a central HV electrode with two ground electrodes. Cells to contain the ultracold neutrons are between the plates and are not visible in the figure. The volume is filled with superfluid ^{4}He surrounded by a superconducting shield. A beam of cold polarized neutrons enters the apparatus from the right. Those neutrons that downscatter in liquid ^{4}He [9] and are trapped in the target cells are used in the measurement. The expected density is ~500 UCN/cm^3 at LANL and a storage time of 500 s is assumed. The spins of the UCN will be rotated by 90° by a $\pi/2$ pulse and then they will precess about a static magnetic field that is parallel to the strong E field. The volume-averaged magnetic field will be monitored by a dilute mixture of polarized ^{3}He in the cells. SQUIDS will be used to measure the spin precession frequency of the ^{3}He. The UCN and ^{3}He precess at slightly different rates and the relative alignment of the spins is detected by neutron capture on ^{3}He because the capture cross section is spin dependent. Scintillation light in ^{4}He from energy deposited by the capture products can reveal a frequency shift when the E field is reversed. The (2σ) limit of the LANL experiment is expected to reach 9×10^{-28} e-cm and will be at least 2×10^{-28} e-cm after the experiment is moved to the SNS, which is under construction at ORNL.

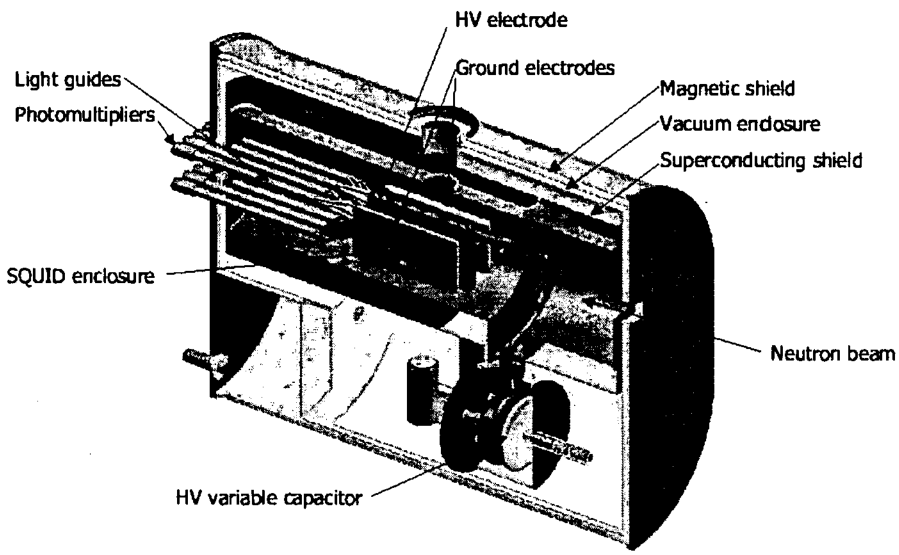

FIGURE 3. Schematic of the proposed LANL experiment.

Because the experiment will employ several advances in technique to reach its goals, the feasibility of meeting these technical challenges is currently under study. The challenges include requirements on the uniformity of the distribution of ^{3}He in the cell, on the uniformity of the E and B fields, and on the noise level for the SQUIDS, etc. The distribution of ^{3}He in liquid ^{4}He was the subject of a test run at LANSCE and a uniform distribution was measured. A byproduct of this test is a measurement of the diffusion coefficient of ^{3}He in ^{4}He for temperatures below 1 K [10]. The electric and magnetic fields have been modeled using a finite element code and it has been determined that the design requirements of 1% uniformity for the E field and 0.1% uniformity for the B field can be met with the apparatus shown in Fig. 3. The SQUID noise measurements have been reported in Ref. 11 and show that the design requirement of less than 5 $\mu\Phi_0/\mathrm{Hz}^{1/2}$ can be achieved.

An apparatus to produce a beam of polarized ^{3}He is being constructed and studies are being planned to determine how to transport and store the ^{3}He without losing polarization. An apparatus to purify ^{4}He has been assembled and will be put into operation soon. A number of topics related to the high voltage are being addressed.

HIGH VOLTAGE TEST

A test apparatus is being constructed as shown in Fig. 4. In addition to validating the variable capacitor concept for this application, the apparatus will serve as a test bed for several engineering issues and for materials studies. The central volume containing the HV and ground electrodes will be filled with liquid ^{4}He. The HV electrode will be charged to 50 kV while the ground electrode is close to the HV plate. Then the HV contact actuator will be retracted and the plates will be separated, lowering the capacitance and raising the voltage. The electric field in the gap will be measured using the Kerr effect, i.e. the medium polarization induced by the electric field.

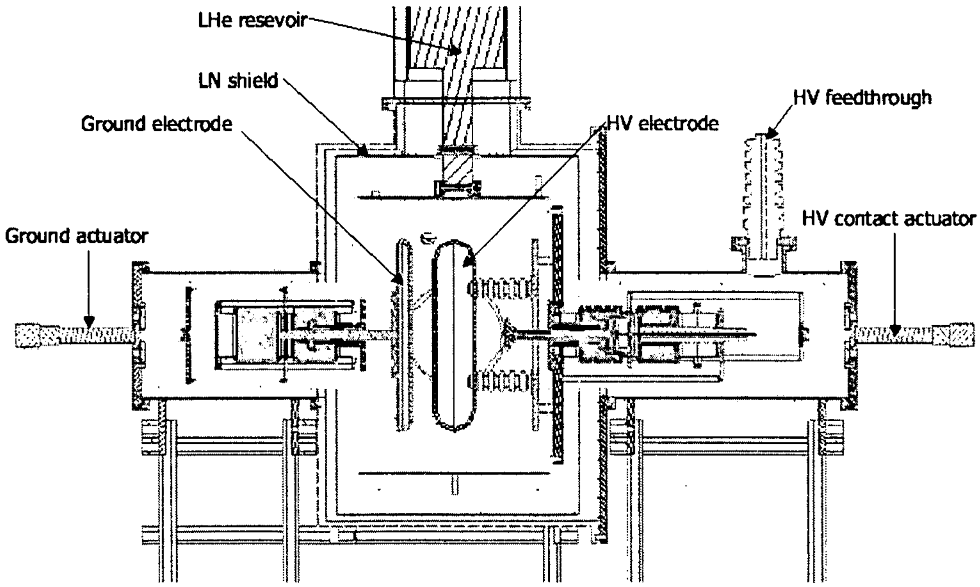

FIGURE 4. Schematic of the high voltage test apparatus.

ACKNOWLEDGMENTS

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